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A general formulation to describe empirical rainfall thresholds for landslides

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Abstract

In this paper, a brief description of the Generalized FLaIR Model (GFM, De Luca and Versace, 2016) is provided, that is able to reproduce all the empirical thresholds proposed in literature, aimed to forecast landslides triggered by rainfall. In particular, this paper focuses on Antecedent Precipitation (AP) schemes. The paper demonstrates that these are particular solutions of the GFM and will exemplify this using AP schemes for NE Italy[1], Seattle[2] and Nicaragua - El Salvador[3].

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Keywords: Landslides triggered by rainfall; non stationary thresholds; Antecedent Precipitation (AP) thresholds

1. Introduction

In technical literature a lot of empirical thresholds have been proposed to forecast landslides triggered by rainfall, which represents an important social-economic issue, in particular for the realization of early warning systems. Many of these empirical thresholds can be grouped in two main classes: 1) Intensity-Duration (ID) relationships[4,5,6,7,8,9,10,11]; 2) Antecedent Precipitation (AP) schemes[12,13,14,2,15,16,17,1,3,18].

ID relationships provide, for different durations, critical values of rainfall intensity that, when reached or exceeded, lead to slope failure, while thresholds belonging to the AP class define critical values of a rainfall event

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aggregated on a short duration (equal to some hours or days before a landslide event), depending on a predisposing antecedent rainfall cumulated over a long duration (equal to several days or months).

ID are usually represented by the well-known power function:

$$I = aD^n \qquad (1)$$

where I is the rainfall intensity, D is rainfall duration, a and n are parameters to be estimated. However, ID thresholds assign the same weight to rain data along the time and, moreover, different precipitation patterns (increasing/decreasing along the time, etc..) with equal mean value of intensity produce the identical results (i.e. exceedance of a critical threshold or non-exceedance). It was demonstrated that FLaIR Model[19] (Forecasting of Landslides Induced by Rainfalls) is able to solve these problems, as it sets different weights to rainfall heights along the time and, furthermore, it reproduces as particular cases all ID thresholds and other schemes like Leaky Barrel[20].

Mathematical expressions, adopted for AP thresholds, are very much variable, depending essentially on the used data. Only in few cases the same analytical structure is used for analyzing different case studies, and then it is possible to investigate the dependence of parameter values on different morphological, geological and climatic contexts. Moreover, short and long durations usually assume different values from one case study to another one. Finally, in all AP schemes an equal weight is set for rain data along the time.

In order to unify this variety of mathematical expressions into an unique framework, the Generalized FLaIR Model (GFM) was proposed[21], which is based on:

- a filter $\psi(.)$, that assigns different weights to rainfall heights as a function of time;
- a function $f[.]$, that defines the relationship between predisposing antecedent precipitation and critical triggering values for a rainfall event.

GFM also reproduces FLaIR model as a particular case, and consequently all the ID thresholds. With respect to FLaIR, the following improvements are provided in GFM: i) it also considers non-stationary thresholds that depend on initial soil moisture of the slope and then on antecedent rainfall; ii) consequently, it is possible to demonstrate that it reproduces all the AP schemes as particular cases; iii) it allows for defining a more general empirical approach which not only uses non-stationary thresholds, as previously mentioned, but also considers filtered rainfall. Consequently, the influence of the rainfall heights, along the time, on landslide trigger is better reproduced, with respect to ID and AP schemes that assign the same weight to all the rainfall data in the investigated time interval; iv) GFM represents a comprehensive framework, as it permits a more rigorous approach compared to the AP schemes, reported in literature, that refer to specific case studies and then usually adopt mathematical expressions very different to each other. More precisely, GFM allows for defining a number of configurations with an increasing number of parameters, and then more and more flexible, among which an user can choose the most suitable, taking into account the need to balance the parametric parsimony and the capacity to reproduce the observed landslide occurrences; v) like FLaIR model, GFM is also suitable for regional analysis.

In this work, concerning some AP cases proposed in literature, authors demonstrated the GFM capacity to describe into a comprehensive framework any empirical scheme, characterized by non-stationary thresholds that depend on initial soil moisture of the slope. The paper is organized as follows: Sect. 2 provides a brief theoretical description of GFM, while examples of AP derivation from GFM are illustrated in Sect. 3. Conclusions are reported in Sect. 4.

2. Brief description of GFM

A mobility function $Y(.)$, defined as a convolution (Eq. 2) between rainfall intensity $I(.)$ and a filter function $\psi(.)$, is adopted, which can be split into a predisposing function $Y_D(.)$ and a triggering function $Y_d(.)$:

$$Y(t) = \int_{t-(d+D)}^{t} I(\tau)\psi(t-\tau)d\tau = \int_{t-(d+D)}^{t-d} I(\tau)\psi(t-\tau)d\tau + \int_{t-d}^{t} I(\tau)\psi(t-\tau)d\tau = Y_D(t-d) + Y_d(t) = \frac{R_D^*(t-d)}{D} + \frac{R_d^*(t)}{d} \qquad (2)$$